OPTIMIZING TECHNIQUES FOR BOTTLENECK TRANSPORTATION PROBLEM WITH MIXED CONSTRAINTS

A Synopsis

Submitted for the partial fulfilment of the requirements for the degree of

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in
Mathematics

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2019

1. Introduction

Transportation Problem (TP)

Transportation Problem (Classical Transportation Problem) (TP) is one of the most important and popular applications of the linear programming (LP) problem. It refers to a class of linear programming problems that involves selection of most economical shipping routes for transfer of a uniform commodity (goods) from a number of sources (factories) $S_i,\ i = 1,2,3 \ldots n$ to a number of destinations (warehouses) $D_j\ , j = 1,2,3, \ldots m$. The amount a_i to be sent from each source, the amount b_j to be received at each destination, and the transporting cost c_{ij} per unit shipped from any source to any destination are specified. The transportation problem is to find the amount of commodity x_{ij} transported from i^{th} source S_i to j^{th} destination D_j which minimises over all transporting cost satisfying demand and supply restrictions. In this problem objective function is linear in decision variables x_{ij} and all the source constraints and destination constraints are of equality type. It is known as the balanced transportation problem if the total supplying capacity of all the sources is equal to total demand of all the destinations, otherwise unbalanced. Mathematical symbols used in transportation problem are shown in the following transportation table 1.

Transportation Table 1

Sources ↓	D_1	D_2	…	D_j	…	D_n	Supply
S_1	$c_{11}[x_{11}]$	$c_{12}[x_{12}]$	…	$c_{1j}[x_{1j}]$	…	$c_{1n}[x_{1n}]$	a_1
S_2	$c_{21}[x_{21}]$	$c_{22}[x_{22}]$	…	$c_{2j}[x_{2j}]$	…	$c_{2n}[x_{2n}]$	a_2
…			…				
S_i	$c_{i1}[x_{i1}]$	$c_{i2}[x_{i2}]$	…	$c_{ij}[x_{ij}]$	…	$c_{in}[x_{in}]$	a_i
…			…		…		
S_m	$c_{m1}[x_{m1}]$	$c_{m2}[x_{m2}]$	…	$c_{mj}[x_{mj}]$	…	$c_{mn}[x_{mn}]$	a_m
Demand (b_j)	b_1	b_2	…	b_j	…	b_n	

Mathematical formulation of classical transportation problem is to find x_{ij} which

$$Minimize\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$$

Subject to

$$\sum_{i=1}^{m} x_{ij} = a_i \ \ for\ i = 1,2,\dots m$$

$$\sum_{i=1}^{m} x_{ij} = b_j \ \ for\ j = 1,2,\dots n$$

$$x_{ij} \geq 0 \quad \text{for all } (i,j).$$

Where c_{ij}= Unit transportation cost from i^{th} source to j^{th} destination

a_i = Amount of goods available at i^{th} source.

b_j = Amount of goods required at j^{th} destination.

x_{ij}= Amount to be transported from i^{th} source to j^{th} destination.

m = Number of sources.

n = Number of destinations.

$S_i = i^{th}$ source

$D_j = j^{th}$ destination

In addition, if the sum of supplies is equal to the sum of demands, that is

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$$

then the problem is said to be balanced transportation problem, otherwise it is unbalanced problem.

In unbalanced transportation problem a dummy row for the case of demand greater than supply and a dummy column for the case of supply greater than demand, are respectively introduced to make the problem balanced.

Initial basic feasible solution of classical transportation problem is obtained by any one of the following methods namely, North West Corner Method, Least Cost Method, Vogel's Approximation Method and the optimality of the solution is checked by MODI Method or Stepping Stone Method [2].

Transportation problem with mixed constraints (TP-MC)

In practical life, it is seen that the supplying capacity of the supply points does not remain constant all through due to the excess and shortage of manpower, machines, raw materials etc., involved in production. In this situation sources impose some restrictions on their supplying capacity like as at least or at most or equal to the fixed amount. Similar restrictions occur for the demand of destinations also due to the variable amount of consumption of commodity. Transportation problem with such restrictions on sources and destinations is termed as transportation problem with mixed constraints. In this problem some source constraints are of 'equal to' type, some are of 'greater than or equal to' type, some are of 'less than or equal to'

type. Destination constraints are also in the same fashion. Transportation problem with such type of constraints is said to be transportation problem with mixed constraints. In this problem objective function is linear in decision variables and constraints are of mixed type linear inequalities in decision variables.

In real life, most of the transportation problem have mixed constraints, like job scheduling, production inventory, production distribution, allocation problems, and investment analysis.

Mathematical symbol used in transportation problem with mixed constraints are presented in transportation table 2.

Table 2

Sources ↓	D_1	D_2	..	D_j	…	D_n	Supply(a_i)
S_1	$c_{11}[x_{11}]$	$c_{12}[x_{12}]$	..	$c_{1j}[x_{1j}]$	…	$c_{1n}[x_{1n}]$	≥/=/≤a_1
S_2	$c_{21}[x_{21}]$	$c_{22}[x_{22}]$	..	$c_{2j}[x_{2j}]$	…	$c_{2n}[x_{2n}]$	≥/=/≤a_2
...			...				
S_i	$c_{i1}[x_{i1}]$	$c_{i2}[x_{i2}]$	..	$c_{ij}[x_{ij}]$	…	$c_{in}[x_{in}]$	≥/=/≤a_i
...			...		...		
S_m	$c_{m1}[x_{m1}]$	$c_{m2}[x_{m2}]$	..	$c_{mj}[x_{mj}]$	…	$c_{mn}[x_{mn}]$	≥/=/≤a_m
Demand (b_j)	≥/=/≤b_1	≥/=/≤b_2	..	≥/=/≤b_j	…	≥/=/≤b_n	

The mathematical formulation of transportation problem with mixed constraints is to find x_{ij} which

$$Minimize\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \geq a_i \qquad i \in P_1$$

$$\sum_{j=1}^{n} x_{ij} = a_i \qquad i \in P_2$$

$$\sum_{j=1}^{n} x_{ij} \leq a_i \qquad i \in P_3$$

$$\sum_{i=1}^{m} x_{ij} \geq b_j \qquad j \in Q_1$$

$$\sum_{i=1}^{m} x_{ij} = b_j \qquad j \in Q_2$$

$$\sum_{i=1}^{m} x_{ij} \leq b_j \qquad j \in Q_3$$

$$x_{ij} \geq 0 \qquad (i,j) \in I \times J$$

where $a_i > 0, \forall\, i \in I$; $b_j > 0, \forall\, j \in J$,

I = $P_1 \cup P_2 \cup P_3$ = the index set of supply points = {1, 2…., m}

J = $Q_1 \cup Q_2 \cup Q_3$ = the index set of destination points = {1, 2….., n}.

Some methods for solving are available in Akilbasha et al. 2017 [1], Klingman and Russell 1974 [5], Brigden 1974 [10], Pandian and Natarajan 2010 [13], Mandal et al.2012 [17], Mandal and Hossain [18], Adlakha et.al 2006 [23].

Generally, it is solved by introducing dummy source and dummy destination to transform it into an equivalent classical transportation problem. The optimal solution of equivalent classical transportation problem is converted into the optimal solution of transportation problem with mixed constraints using transformation rule.

There are some situations, where paradox occurs. The more-for-less paradox in a transportation problem with mixed constraints occurs when more flow with lesser cost than the flow corresponding to the optimal cost is possible in transportation problem with mixed constraints.

Bottleneck Transportation Problem (BTP)

In Production and Project Management, A Bottleneck is one process in a chain of processes such that its limited capacity reduces the capacity of the whole chain. The result of having a bottleneck are stalls in production, supply overstock, pressure from customers and low employee morale.

The Bottleneck Transportation Problem (BTP) (classical bottleneck transportation problem) or Time Minimizing Transportation Problem (TMTP) is defined as a Classical Transportation Problem (TP) in which a time t_{ij} , $i = 1,2, \dots m;\ j = 1,2, \dots n$ is associated with each shipping route rather than cost as shown in transportation table 3. The objective of the problem is to minimize the maximum time of transporting all supplies to the destinations satisfying the demand and supply conditions. Remaining assumptions on sources and destinations are same as that of classical transportation problem.

The BTP is encountered in connection with transportation of perishable stuff, medical treatment equipment's, emergency provisions, fire services and military equipment's, where speed of delivery is highly essential than the transportation cost.

Mathematical symbol used in BTP are shown in transportation table 3

Table 3

	D_1	D_2	….	D_j	….	D_n	supply
S_1	$t_{11}[x_{11}]$	$t_{12}[x_{12}]$	….	$t_{1j}[x_{1j}]$	….	$t_{1n}[x_{1n}]$	a_1
S_2	$t_{21}[x_{21}]$	$t_{22}[x_{22}]$	….	$t_{2j}[x_{2j}]$	….	$t_{2n}[x_{2n}]$	a_2
….	…….	…….	….	……	….	…….	…
S_i	$t_{i1}[x_{i1}]$	$t_{i2}[x_{i2}]$	….	$t_{ij}[x_{ij}]$	….	$t_{in}[x_{in}]$	a_i
….	…….	……..	….	…….	….	…….	
S_m	$t_{m1}[x_{m1}]$	$t_{m2}[x_{m2}]$	….	$t_{mj}[x_{mj}]$	….	$t_{mn}[x_{mn}]$	a_m
Demand	b_1	b_2	….	b_j	….	b_n	

Mathematical formulation of Classical Bottleneck Transportation Problem is to find x_{ij} and t_{ij} which

$$Minimize\ Z = \max_{i,j}\{t_{ij} : x_{ij} > 0\}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} = a_i \qquad i = 1,2, \ldots \ldots m$$

$$\sum_{i=1}^{m} x_{ij} = b_j \qquad j = 1,2, \ldots \ldots n$$

$$x_{ij} \geq 0$$

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$$

Where a_i = amount available at the i^{th} supply point,

b_j = requirement at the j^{th} demand point,

t_{ij} = transportation time from supply point S_i to demand point D_j,

x_{ij} = amount to be transported from the i^{th} supply point to the j^{th}demand point,

and all the data is integer.

NIKOLIC 2007 [8], Sharma and Swarup 1977 [9], Jain and Saksena 2012 [11], Ahmed et al. 2015 [12] have worked on time minimizing transportation problem with equality constraints

2. Bottleneck Transportation Problem with Mixed constraints (BTP-MC)

In real life, most of the bottleneck transportation problem appears with mixed constraints due to changing economic and environmental conditions of producers and distributors. Different sources and destinations impose different limitations (≥/=/≤) on supply and demand respectively according to their availability and requirement. Bottleneck transportation problem in which source constraints and destination constraints are of mixed nature is said to be bottleneck transportation problem with mixed constraints.

Mathematical Symbols used in BTP-MC are shown in table 4

Table 4

	D_1	D_2	….	D_j	….	D_n	supply
S_1	$t_{11}[x_{11}]$	$t_{12}[x_{12}]$	….	$t_{1j}[x_{1j}]$		$t_{1n}[x_{1n}]$	≥/=/≤a_1
S_2	$t_{21}[x_{21}]$	$t_{22}[x_{22}]$	….	$t_{2j}[x_{2j}]$		$t_{2n}[x_{2n}]$	≥/=/≤a_2
….	…….	…….	….			…….	…
S_i	$t_{i1}[x_{i1}]$	$t_{i2}[x_{i2}]$		$t_{ij}[x_{ij}]$		$t_{in}[x_{in}]$	≥/=/≤a_i
….							
S_m	$t_{m1}[x_{m1}]$	$t_{m2}[x_{m2}]$	….	$t_{mj}[x_{mj}]$		$t_{mn}[x_{mn}]$	≥/=/≤a_m
Demand	≥/=/≤b_1	≥/=/≤b_2	….	≥/=/≤b_j		≥/=/≤b_n	

The mathematical model for BTP-MC is to find t_{ij} and x_{ij} which

$$Minimize\ z = \max_{i,j}\{t_{ij} / x_{ij} > 0\}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \geq a_i \qquad i \in P_1$$

$$\sum_{j=1}^{n} x_{ij} = a_i \qquad i \in P_2$$

$$\sum_{j=1}^{n} x_{ij} \leq a_i \qquad i \in P_3$$

$$\sum_{i=1}^{m} x_{ij} \geq b_j \qquad j \in Q_1$$

$$\sum_{i=1}^{m} x_{ij} = b_j \qquad j \in Q_2$$

$$\sum_{i=1}^{m} x_{ij} \leq b_j \qquad j \in Q_3$$

$x_{ij} \geq 0;\ a_i > 0$, $\forall$ i $\in$ I; $b_j > 0$, $\forall$ j $\in$ J

I= $P_1 \cup P_2 \cup P_3 = \{1,2,3, \ldots, m\}$ = set of index of supply points.

J= $Q_1 \cup Q_2 \cup Q_3 = \{1,2,3, \ldots\ldots, n\}$ = set of index of demand points.

It is assumed in the proposed problem that

(i) The carriers have enough capacity to carry goods from an origin to a destination in a single trip

(ii) They start simultaneously from their respective origins.

The objective function is nonlinear function of time. Non linearity in objective function and mixed type nature of constraints creates some complexity in its solution methods. This problem is rarely seen in literature. A single paper of Agarwal and Sharma 2014 [22] appear in

literature for optimal solution of time minimizing transportation problem with mixed constraints.

3. Applications of Bottleneck Transportation Problem with Mixed Constraints.

The bottleneck transportation problem with mixed constraints have a great importance from practical standpoint due to change of economic and environmental scenario, and are encountered in many practical situations:

(i). **Transportation of perishable goods**- In the transportation of perishable items such as fresh fruit, vegetables, milk, etc., the duration of delivery is crucial. As any time, lag in transportation may result in much larger loss than any cost advantage attained by transporting it at lower cost.

(ii). **Transportation of military equipment**: - In military transportation, at the time of emergency, military arrangements or weapons are required to be delivered from their military bases to battlefronts, where time of transportation is of prime consideration.

(iii). **Transportation of emergency relief goods**: - At the time when natural calamities like earth quake, floods, tsunami, etc., strike emergency relief goods are required to be transported in minimum time. As a brief delay may cause massive loss of lives.

(iv). **Transportation of medical supplies**: - In hospital transportation, ambulances, medicines, blood (or blood products) and other medical supplies are need to be timely delivered.

4. Literature Review

The Transportation problem was first formulated mathematically by F.L. Hitchcock in 1941 and discussed in detail by the Nobel Laureate T.C. Koopmans in 1947 paper. The linear

programming formulation of the transportation problem and associated solution procedure were first given by G.B. Dantzig in 1951.

Hammer 1969 [15] has given a method for finding those solution of a transportation problem which minimize the total time necessary for transporting goods from the suppliers to the consumers. Several extensions of the model are presented.

Garfinkel and Rao 1971 [16] has developed two algorithms for solving the bottleneck transportation problem with equality constraints. One of them is a primal approach in the sense that improving feasible solutions are obtained at each iteration. The other is a "threshold" algorithm which is found to be far superior computationally.

Klingman and Russell 1974 [5] studied to generalization of the standard transportation model in which the origin and destination constraints consist not only of equality but also inequality constraints. It is shown that the model is equivalent to a standard transportation problem having only one additional origin and destination.

Sharma and Swarup 1977 [9] developed a procedure for time minimization in TP and consists of a finite number of iterations and is based on moving from a basic feasible solution to another till the last solution is arrived at.

Bottleneck Transportation problem (BTP) is considered by Wild JR et al. 1992 [4] where bottleneck is computed for each demand point. Due to the existence of local optimal, solution procedures that have been developed for BTP do not readily apply to the Multiple Bottleneck Problem (MTP). An effective solution technique that uses Lagrangean relaxation method is described and tested.

S. Geetha and K.P.K Nair 1994 [19] considered a stochastic bottleneck transportation problem, which aims at minimizing the transportation time target subject to a chance constraint, is formulated and an algorithm based on a parametric programming approach is developed to solve it.

Tkachenko and Alhazov 2001 [3] find the solution methods for a multicriterial transportation problem of a non-linear type.

Ilija 2006 [8] considered the total time minimizing transportation problem. This paper shows the total transportation time problem regarding the time of the active transportation routes. If the multiple optimal solutions exist, it is possible to include other criteria as second level of criteria and find the corresponding solutions. Furthermore, if there is a multiple solution, again, the third objective can be optimized in lexicographic order. The methods of generation of the optimal solution in selected cases are developed. The numerical example is included.

Adlakha et al. 2006 [23] developed a heuristic algorithm for solving transportation problem with mixed constraints and extended the algorithm to find a more- for- less (MFL) solution, if one exists.

Pandian and Natarajan 2010 [13] had developed a method to find an optimal more- for - less (MFL) solution for transportation problems with mixed constraints. The optimal MFL solution procedure is illustrated with numerical example.

Pandian and Natarajan 2011[14] had developed blocking method for finding an optimal solution to bottleneck cost minimizing transportation problems.

Jain and Saksena 2012 [11] studied Time Minimizing Transportation Problem with Fractional Bottleneck Objective function (TMTP-FBOF). TMTP-FBOF is related to a Lexicographic Fractional Time Minimizing Transportation Problem (LFTMTP), which will be solved by a lexicographic primal code. An algorithm is also developed to determine an initial efficient basic solution to this TMTP-FBOF.

Mondal et al. 2012 [17],[18] had described an algorithm to find an optimal More- for - less MFL solution for transportation problem with mixed constraints.

Agarwal and Sharma 2014 [22] considered TMTP-MC problem which minimizes the maximum time of duration to accomplish the requirements of n demand points using the capacity of m supply points. An open loop method has been developed for improving the initial basic feasible solution by shifting the basic cells to other basic cells or non- basic cells having less time.

Kumar and Kumaraghuru 2015 [20] analyses the blocking Method for finding an optimal solution to Fuzzy Bottleneck transportation Problem which is very different from other methods and obtained the efficient solutions of fuzzy BTP by using Blocking Zero-point method.

Ahmed et al. 2015 [12] had developed a transportation algorithm to obtain a better initial basic feasible solution in time minimizing transportation problem.

Acharya et al. 2015 [6] discussed paradox in a nonlinear Transportation Problem, thereby, they established a enough condition for the existence of paradox in a non-linear transportation problem. They had found out the paradoxical range of flow as well as paradoxical flow for a specified flow.

Akilbasha et al. 2017 [1] developed a new method, rough slice -sum method for solving fully rough integer interval transportation problem.

ISHII and SATO 2017 [7] studied multi-objective bottleneck transportation problem with fuzzy random constraints about transportation time and chance constraints about the total cost.

Agarwal and Sharma 2018 [21] had developed a method for finding IBFS (initial basic feasible solution) of TMTP-MC. They relate the time minimizing transportation problem with mixed constraints to a transportation problem with equality constraints balanced problem with equality constraints.

5. Proposed Work

Literature search reveals that there is no systematic method for finding an optimal solution or addressing more for less situations in transportation problems with mixed constraints.

We have gone through several research papers directly or indirectly related to bottleneck transportation problem. A lot of work has been done on classical bottleneck transportation problem (time minimizing transportation problem with equality constraints). But only a single paper of Agarwal and Sharma (2014) appeared in literature for optimal solution of TMTP-MC. They have developed a method for solving TMTP-MC by introducing an open loop. No other than paper has been seen in the Literature on TMTP-MC.

We proposed to develop some optimization techniques of Bottleneck Transportation Problem with Mixed Constraints. We have searched some directions along which proper and efficient methods and an attempt would be made to develop an optimal solution of Bottleneck Transportation Problem with Mixed Constraints.

Pandian and Natarajan (2011) [14] has developed a method for finding an optimal solution to bottleneck-cost transportation problem. In this method, they block some cells which have more time unit than the maximum of row and column minima from time minimizing transportation table and then allot the maximum possible to a cell having only one unblocked cell in the row/column. And then, modify the active transportation table and repeat the process until the required optimal solution is obtained. We are going to extend this idea for minimizing the duration of transportation time in Bottleneck Transportation Problem with mixed constraints by blocking the highest time cell, second highest time and so on as long as feasibility of the problem sustains, to reduce maximum shipment time in order to get the optimal solution.

Agarwal and Sharma (2018) [21] has developed a shootout method for finding a basic feasible solution for TMTP-MC . In this method cells of transportation table with decreasing

order of time are avoided one by one for allotment if feasibility sustains. In this method assignment technique of remaining cells is not so much easier. We will modify this method of removing the cells and assigning the remaining cells in a proper and efficient way so that a simple method may be developed for bottleneck transportation problem with mixed constraints.

Agarwal and Sharma (2014) [22] has developed an Open Loop method for TMTP-MC. In this method an open loop is created initiating from a basic cell to a non-basic cell to exchange them. Keeping this idea in mind, a method for getting an optimal solution of Bottleneck Transportation Problem with mixed constraints will be developed. We are going to develop a method for improving basic feasible solution to get an optimal solution of Bottleneck Transportation Problem with Mixed Constraints, by the exchange of a basic and a non-basic variable.

Acharya et al. (2015) [6] discussed paradox in a nonlinear transportation problem. They have developed a sufficient condition for the existence of paradox in non-linear Transportation Problem. They have obtained paradoxical range of flow as well as paradoxical flow for a specified flow. Using the idea of more flow for lesser cost we analyse more flow for less time solution of bottleneck transportation problem with mixed constraints.

All the methods will be presented in the form of respective algorithms and they will be codded in MATLAB/C. Various numerical illustrations will be carried out for testing the efficiency of the algorithms manually as well as computationally.

Comparative study of all the proposed methods will be made along with their limitations, advantage/disadvantage.

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